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# RESEARCH ARTICLE

# SHORT TERM FREEZE-THAW EFFECTS ON WASTE PLASTIC BAGS AND INDUSTRIAL POLYETHYLENE MODIFIED HOT MIX ASPHALT (HMA)

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**ABSTRACT**

Environmental and climate conditions are two very important factors that affect flexible asphalt pavements in roads. Asphalt Pavements (AP) are usually under continuous expansion and contraction effects from the nonstop increases and decreases of temperatures. As a result, AP structures are subjected to critical stresses and strains leading to cracks and defects. The physical and mechanical properties of hot mix asphalt (HMA) must be improved to resist the thermal cracking defects that generally occur in a pavement's asphalt. Meanwhile, many types and huge quantities of waste plastics and industrial polyethylene are being generated. These wastes are harmful to the environment. This research aims to improve HMA specimen's properties by adding waste plastic bags and industrial polyethylene to pure asphalt with replacement percentages of 2%, 3%, 4%, 5%, and 6% by total weight of asphalt. The optimal contents of additives to asphalt were found to be 4.6% and 4.1% for waste plastic bags and polyethylene, respectively. The effect of the short term freeze–thaw cycle on asphalt mixtures with and without additives was also studied. Durability curves and indexes were used to find the resistances of mixtures against freeze–thaw stresses. Three types of asphalt mixtures were prepared according to the Marshall method; all were exposed to freeze-thaw cycles according to the following timetable (1, 2, 3, 4, and 5) cycles, where each cycle represent 48 hours (24 hours freezing and 24 hours thawing). The first durability index (FDI) for asphalt mixtures with polyethylene had a lower loss rate in stability in one day, at 30.86 %, followed by asphalt mixtures with waste plastic bags where the value of FDI was 38.59%, while asphalt mixtures without additives gave an FDI value of 55.22%. Adding polyethylene and waste plastic clearly improves the mixtures properties and in turn increases the durability of asphalt pavements.



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## INTRODUCTION

One of the most important factors for selecting a pavement category is the local environmental conditions (moisture, temperature), as volume changes caused by excessive moisture content or an extended freeze-thaw cycle can produce cracking; while generally associated with wheel load, shear failures can occur in paving materials and subgrades (Queensland department of transport and main roads, 2017). Asphalt mixture exhibits excessive temperature susceptibility: at high temperature it becomes softer leading to rutting, at medium temperature fatigue cracks appear and low temperatures lead to thermal cracks (Sulyman, 2016). Therefore, adding supporting materials to asphalt has been investigated in multiple studies. Waste plastics is one of these materials, as its use offers a great potential in asphalt road construction, adding in small quantities, approximately 5-10% by asphalt weight (Prasad, 2015). In general, polymers are added to the mix at a ratio of 3–8% by total weight of the binder (Ibrahim, 2005).

The correct selection of additives for a particular highway project depend on interrelated factors comprising the ability of the construction team, availability of materials, cost, and the desired performance (Johnson Kwabena Appiaha, 2017). Durable and long-lasting asphalt pavements are obviously preferred, as they improve safety and comfort by their riding surface as well as associated decreased maintenance costs. However, improving asphalt mixture design alone is insufficient to guarantee a good quality pavement. Accurate and effective characterization of pavement material is crucial to understanding the behavior or response of these asphalt mixtures under external stimuli of traffic loading as influenced by construction quality and environmental conditions (Wan Mohd Nazmi Wan Abdul Rahman, 2016).The surface course provides several characteristics such as smoothness, skid-resistant surface, rut resistance, flexibility and drainage. In addition, it serves as a waterproof layer to protect the entire flexible pavement from seeping large amounts of surface water into the underlying base course, sub base course and sub grade (Georgia Department of Transportation, 2005). The most common distresses that occur in flexible asphalt pavement are cracking. Cracking in surface course of flexible pavements can be categorized into one of three major categories: surfacing cracks, fatigue cracks and others (transverse, longitudinal, edge, reflection cracks). Low-temperature cracking of a surface course begins as the ambient temperature drops to a very low level. A pothole represents a typical example of the collaboration of three mechanisms: excessive repetitions of heavy load wheels, weakening of the sub-base and sub grade, and the freeze-thaw cycle (Taylor & Francis Group, 2006). AP has been mainly used as a construction material in highways. Under the effects of a repeated number of vehicles at very high temperature, excessive moisture, and very cold temperature contraction, an AP mixture is subject to several distresses such as permanent deformation (rutting), loss of asphalt film from aggregates (stripping), and cracking (Qinwu Xu, 2010). Cracks may be produced by major climatic changes (either high temperature or very low temperatures). Hot mix asphalt (HMA) suffers greatly from longitudinal or transverse cracks as a result as temperature stresses if the bitumen in the HMA is of a type that quickly becomes stiff and brittle at low temperatures. Water infiltration into the void spaces and the freezing-thawing cycle usually results in a determinate surface course which is accelerated under traffic conditions and thus leads to the breakdown of HMA (Richard Robinson and Bent Thagesen, 2004).

Additives may be used to modify the engineering properties (e.g. durability, strength) of asphalt cement and improve the performance of AP (Taylor, 2006). One of the most important ways to eliminate waste plastic is by mixing it with asphalt. Currently, HMA modified with polymers is being used in many parts of the world. Adding polymers into HMA mixtures typically leads to an increase in the asphalt stiffness as well as an improvement in its temperature susceptibility, thereby increasing its resistance against permanent deformation. Another use of polymers is in the production of a coated material for aggregate, which produces HMA mixtures that are more resistant to polishing as it increases the roughness of the surfaces aggregate (Ibrahim, 2005; Wan Mohd Nazmi Wan Abdul Rahman, 2016). Plastic polymers are mostly used for plastic products such as bottles, bags and cups, mainly prepared of polypropylene, polyethylene and polystyrene (Rajasekaran, 2013). The municipal solid-waste (MSW) produced in the USA is 200 x $10^6$ tons per year (according to data from the U.S. Environmental Protection Agency), 38%wt are paper products, 8%wt waste plastic, and about 3% wt textiles and carpets. (Sulyman, 2016). The formation of non-decaying waste resources such as plastics (bottles or bags), fly-ash, scrap tires, steel slag, etc., have been posing serious challenges in waste management, inspiring construction engineers and highway designers to search for new solutions by adding waste plastics in concrete pavement, flexible pavement and solid blocks (Vanitha, 2015).

## LITERATURE REVIEW

Researchers in both industry and academia have sought to explore the properties of modern industrial materials and waste materials and reuse them in road construction. Paul and Bhattacharya (Rajdip Paul, 2015) carried out a series of tests on modified and unmodified asphalt mixtures with varying percentages of waste plastic as additives. The stone aggregates were coated with molten waste plastics. They state that the covering of aggregates with plastics reduced the air voids and water absorption as well as improving soundness and durability, resulting in a decrease in deformation (rutting) and raveling and eliminating stripping formation. The modified asphalt pavement can withstand heavy load traffic and offers better performance. Kalantar *et al.* (Zahra Niloofar, 2011) investigated the advantages of adding waste plastic bottles (WPB) as additives in asphalt cement. The modified asphalt mixes were prepared by blending the WPB in proportions of 2%, 4%, 6%, 8% and 10% by weight of asphalt. They stated that usage of WPB decreases temperature susceptibility compared to conventional asphalt; this advantage is attributed to the resistance of modified asphalt to cracking when subjected to temperature change. Rokade (Rokade, 2012) evaluated the result of blending low-density polyethylene (LDPE) and Crumb Rubber (CRMB) into asphalt mixes as modified additives, and found that that the usage of LDPE and CRMB increased the Marshal Stability by close to 25%. This increase in stability results in longer serviceability and durability for the surface course.

Mishra and Mishra (Brajesh Mishra, 2007**)** used waste plastic (WP) obtained from treated plastic bags, consisting primarily of polyethene and low-density polyethene (LDPE) mixed into asphalt blends. The results indicated that WP can be suitably be used as an additive for asphalt concrete as it covers the aggregates of the mix, thereby decreasing the porosity and absorption properties and increasing the blending properties of the mixes. The value of Marshall Stability increases with the percentage of plastic until 12% (by weight of asphalt) and declines thereafter. Studies have continued and many attempts have been made to understand and avoid the thermal cracking of asphalt pavement as a result of freezing and thawing cycles and ambient conditions. LaForce *et al.* (2006) concluded that because the vast majority of distress occurs in the area along the longitudinal construction joint, the early failure of the pavement was due to inadequate construction joint densities caused by high mix stiffness during compaction and a lack of mix resistance to repeated freeze-thaw stress. Pradeep soyal (2015) used low polythene material (LDPE) as a modified binder, utilizing waste plastic collected from packaging pouches of drinking water to assemble the required amounts of LDPE to be added to specific amounts of asphalt to achieve an optimum percentage of asphalt-polythene blend. The results showed that the use of LDPE in asphalt concrete improves its mixture properties; achieving better coating for the mixture's aggregate and thereby reducing both its porosity and moisture absorption. The Marshall Stability was increased by about 35% compared to a control mix when blended with 4% LDPE. The same results were obtained by Bindu and Beena (2010) when they studied the feasibility of blending shredded waste plastics with asphalt concrete. The stability value of their modified mix was close to 30% greater than that of the unmodified mix. They also found less hardening with bitumen aging and less moisture absorption, indicating higher resistance to water. In addition, there was a savings of 10% of bitumen content, which leads to economical asphalt pavement design. According to Chavan (2013), recycled plastic grocery bags can be convenient in the construction of asphalt pavements, resulting in decreased permanent deformation (rutting), increasing the strength and performance of the road surface, reducing tripping where there is the possibility of avoiding the use of anti-stripping material, as well as reducing the asphalt content by about 10% (low cost construction). Santosh *et al.* (2013) studied the addition of small pieces of waste plastic cement bags (WPCG). These were blended with hot aggregates (dry process) according to the changed waste plastic percent (2% to 12%) by weight of asphalt. Their results show that incorporating WPCG as a modifier leads to improved engineering properties of asphalt concrete (stability, flow) when added at 8% by weight of asphalt.

**In another investigation, Awwad and Shbeeb:** (Mohammad, 2007) tested adding high-density polyethylene (HDPE) and low-density polyethylene (LDPE) at different percentages (8, 10, 12…18%) of asphalt content to dry aggregates. The results showed that the modified asphalt mixtures have a higher stability value and lower void mineral aggregates compared to mixtures without modified additives. The modified asphalt mixtures also increase fatigue resistance, adhesion with the aggregate and rutting resistance.

## MATERIAL AND METHODOLOGY OF THE STUDY

A 60/70 penetration grade asphalt was selected, based on the common environmental conditions of 4.5, 5, 5.5, 6, 6.5, 7 and 7.5 percent by total weight of mix. Waste plastic bags (WPB), consisting of colored and transparent carry bags, were obtained from residential areas. These WPBs were shredded into small particles of between 1 to 3 mm, with a value of specific gravity of 0.96 (ASTM D792). The industrial polyethylene is a low-density polyethylene (LDPE) from a local plastic factory with a specific gravity of 0.94 (ASTM D792). The LDPE and the WPB was mixed with the asphalt according to the following method. The shredded WPB and LDPE were added separately to the hot asphalt at temperature of between (160 - 170 °C). Each were agitated with an asphalt puree at gentle mixing speeds. This process resulted in a uniform within 25 to 30 seconds. Dfferent percentages of OAC were partially (2%, 3%, 4%, 5%, and 6%) replaced by LDPE and WPB. Two types of modified asphalt mixes were produced; asphalt-WPB mix and asphalt-LDPE mix, and were then added over the hot aggregate (155 °C in an oven for 2 hours). The optimum asphalt-WPB content and optimum asphalt-LDPE content were then found by evaluating the mixtures' performance.

All of the modified asphalt mixtures were compacted by 75 blows on the top and the bottoms of the specimens. To study the effect of freezing and thawing on asphalt mixtures, the following procedure was utilized: 15 samples of each type of mixture were prepared, placed in a freezer to expose them to -18 $^{O}$C for 24 hours, these samples where then extracted and put in a water bath of 60 $^{O}$C for 24 hours. Next, they were immediately tested by the Marshall apparatus. This procedure represents one freeze-thaw cycle. Therefore, the freeze-thaw cycle is 48 hours. For two cycles, the samples were frozen at -18 $^{O}$C for 24 hours and then placed in a 60 $^{O}$C water bath for 24 hours, and then this process was repeated for another full cycle. After these two cycles, the samples were immediately tested by Marshall apparatus. These procedures represent two freeze-thaw cycles; the same process was used to represent three, four, and five cycles. The physical and mechanical properties of the aggregates were tested and measured according to Jordanian specifications. Tables 1 and 2 provide the results of testing the aggregate used in this study. Table 1: Aggregate properties affecting flexible pavement in Jordan. It has a softening point of 51$^{O}$C (ASTM D-36), with ductility value of 72 cm (ASTM D113), flash and fire points of 271 $^{O}$C and 321 $^{O}$C, respectively (AASHTO T48), and a specific gravity of 1.03. The optimum asphalt content (OAC) was 6% of the specimen's weight according to the Marshall Test (ASTM D 1559-89), with asphalt percentages

## RESULTS AND DISCUSSION

**Modified Asphalt Mixtures:** The analysis of the results is designed to determine the optimum asphalt-WPB mix and the optimum asphalt-LDPE mix. The mechanical properties of these mixtures were evaluated after 5 different freeze-thaw cycles. The tested specimens were prepared at an OAC of 6 % by total weight of asphalt. The results of both asphalt-WPB and asphalt-LDPE contents versus Marshall Stability, specific gravity, flow and void ratio are presented graphically in Figures 1, 2, 3, and 4, respectively. The results show that as the LDBE and WPB contents increase the Marshall Stability increases up to a maximum stability and then decreases, as shown in Fig. 1. This behavior can be attributed to the fact that increasing LDBE and WPB contents in mixes improves the sliding of the aggregate, leading to a better interlocking of the aggregates with each other. As the LDBE and WPB contents increases, the specific gravity increases, until it reaches its maximum value, after which the specific gravity decreases, as indicated in Fig. 2. It is clear that as the LDBE and WPB contents increase, the void ratios gradually increase as revealed in Fig. 3. This behavior is due to the formation of small crystal bodies of the chopped LDBE and WPB used in the mix.Flow rate can give an indication of the stiffness of the mix (the higher the stability the smaller the flow and vice versa); a high flow means that the flow is relatively weak. As presented in Figure 4, an increase in the WPB and LDPE cause the flow to decrease until 4.25% of WPB and LDPE and then it turns into an upward movement, this behavior may be attributed to the formation of a harder mixture. Conversely, a high percentage of WPB and LDPE cause the stability decreases while the flow to increase. According to the maximum Marshall Stability and the specific gravity, as well the allowed percentages of void ratio (Va) of 4 % as shown in Figs. 1, 2 and 3, the optimum WPB and LDPE contents are 4.6% and 4.1% (by the pure asphalt weight), respectively. The results clearly show that asphalt modified with LDPE has a higher Marshall Stability of 1617 kg, followed by the asphalt modified with 4.6% of WPB. This leads to the conclusion that using LDPE as an additive is achieves a better result than the same content of WPB. Better Stability would noticeably impact on the rutting and fatigue resistance of the modified asphalt mixtures leading to more sustainable asphalt pavement.

**The Effect of the Freeze-Thaw Cycle on the Stability:** Freeze–thaw cycles greatly affect asphalt stability as shown in Fig. 5. The stability for each mixtures decrease with each additional number of freeze–thaw cycles. The mixtures with LDPE have the highest stability, followed by the WPB adding LDPE and WPB to asphalt mixtures increases the stability and thus improves resistance to freezing-thawing cycles.

**The Effect of Freeze-thaw Cycles on the Flow:** Figure 6 shows that the flow values are the highest for asphalt mixtures without additives and the lowest for LDPE mixtures, with WPB mixture flow values in between the two. LDPE Without additives. The LDPE increases the adhesive and adhesion properties of asphalt, resulting in a higher stability, as confirmed in several studies, including Rokade (2012) and

**Table 1. Aggregate properties**

| Test | | | |
|---|---|---|---|
| L. A. Abrasion (ASTM C131–81) | | 32.17% | |
| Specific Gravity (ASTM C127) | Coarse aggregate 2.47 | Fine aggregate 2.68 | Filler 2.71 |

**Table 2. Aggregate Gradation (Sieve analysis)**

| Sieve # | Passing % |
|---|---|
| 1" | 100 |
| ¾" | 95 |
| ½" | 85 |
| 3/8" | 67 |
| #4 | 42 |
| #8 | 27 |
| #40 | 14 |
| #50 | 9 |
| #100 | 6 |
| #200 | 5.7 |

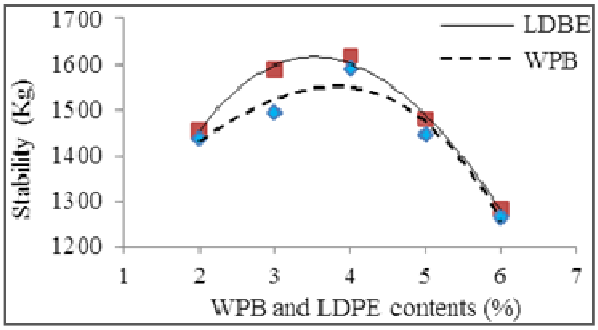


**Fig. 1. Marshall Stability versus LDPE and WPB contents**

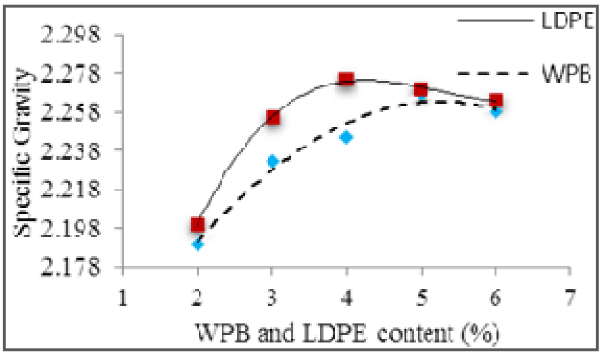


**Fig. 2. Specific gravity versus LDPE and WPB contents**

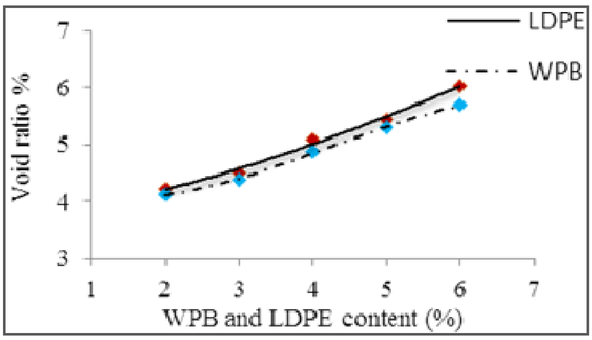


**Fig. 3. Void ratio versus LDPE and WPB contents**

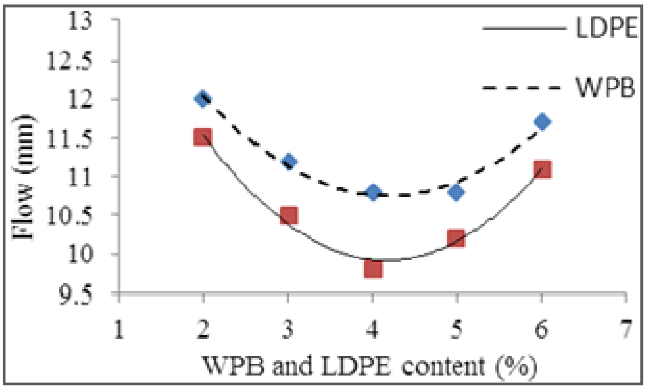


**Fig. 4. Flow versus LDPE and WPB contents**

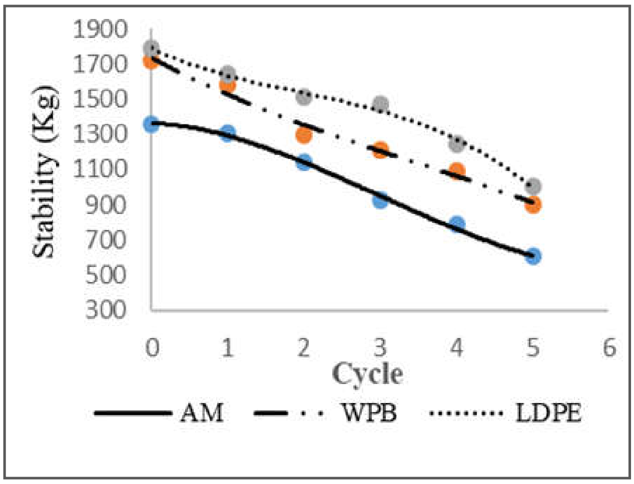


**Fig. 5. Stability versus no. of freezing–thawing cycles**

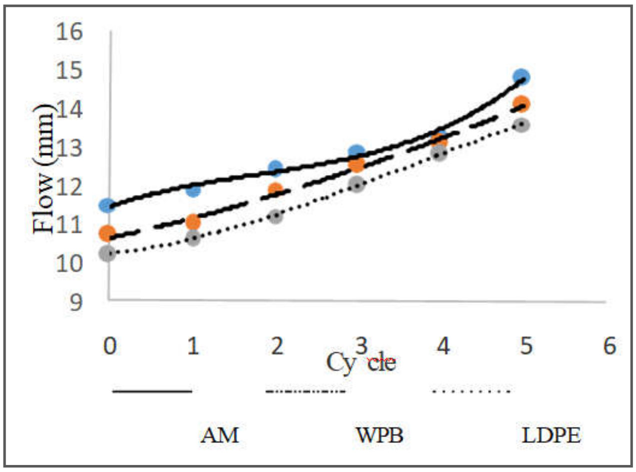


**Fig. 6. Flow versus no. freezing–thawing cycles**

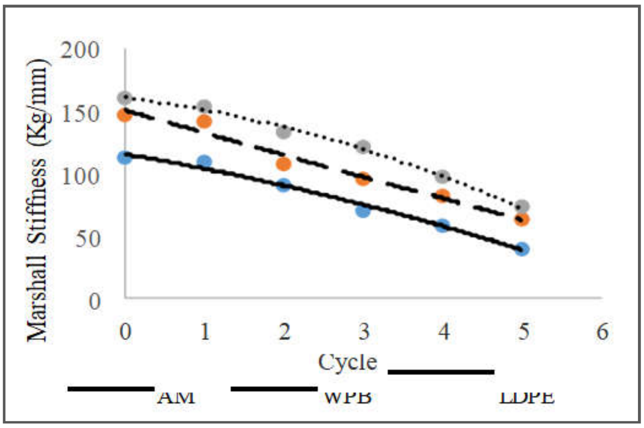

**Fig.7. Marshal Stiffness (KG/mm) versus no. freeze – thaw cycles.**

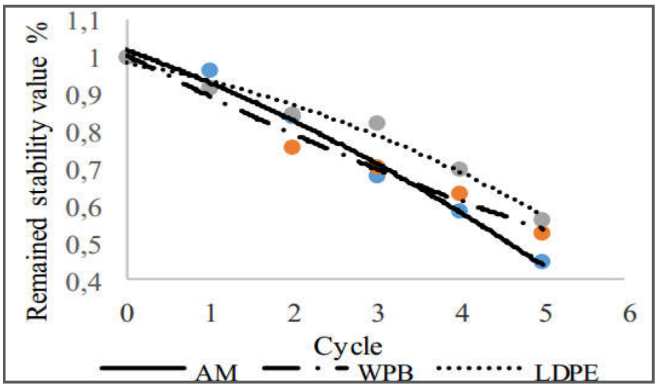


**Fig. 8. Remained Stability (%) versus no. of freezing– thawing cycling**

**Table 3. Remaining Marshall stability with freeze-thaw cycles**

| TYPE | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| AM | 1 | 0.96 | 0.83 | 0.67 | 0.58 | 0.44 |
| WPB | 1 | 0.91 | 0.75 | 0.70 | 0.63 | 0.52 |
| LDPE | 1 | 0.91 | 0.84 | 0.82 | 0.69 | 0.56 |

Santosh *et al.* (2013). Increase the number of freeze-thaw cycles leads to the washing and oxidation of the asphalt film which surrounds aggregates as a result of asphalt binder aging, thus increasing the possibility that the asphalt film may become susceptible to water through pores created in the asphalt- aggregate cohesion. This process is the likely cause for the loss of cohesion. Under frequent freezing and thawing cycles, the confined water inside air voids and pores will increase in its volume, leading to internal tension and It is clear that flow increase with the number of freeze–thaw cycles, as water freezes inside holes and increases the air vides, as discussed previously. There are obvious differences between the LDPE mixtures and asphalt mixtures without additives. The minimum flow value occurs in LDPE mixtures because adding LDPE or adding WPB increases the cohesion property of the asphalt binder and leads to less flow.

**The Effect of Freeze-thaw Cycles on the Marshall Stiffness:** The ratio of the stability to the flow represents the Marshall Stiffness (MS). In general, MS is inversely proportional to the number of freeze- thaw cycles, as shown in Fig. 7. compression stresses; when these stresses are greater than the strength of asphalt–aggregate cohesion the mixtures begin to disintegrate and thus their stability diminishes. It is clear that

The lowest MS is found for a non-additive asphalt mix at 40.8 KG/mm, and the maximum value occurred with a modified asphalt mixture with LDPE of 73.8 KG/mm. In general, modified asphalt mixes have an MS larger than that of conventional mixes because adding LDPE and WPB may increase the adhesion and cohesion properties, these results compatible with those of of J Chavan (Miss Apurva J Chavan, 2013).

**Durability Curve and Index:** The durability index (DI) is widely used to identify the disintegration characteristics of mixtures, as well as to study the resistance against distress when a sample is subject to a environmental and climate conditions such as wetdry cycles, freeze-thaw cycles, and high temperatures. This index is therefore considered an important engineering criterion for evaluating the durability of asphalt mixtures. A higher value of this index implies that a mixture can better withstand deterioration and failure over time. In this work, the remaining percentage of the Marshall Stability was taken as a special criterion to study asphalt mixture durability (Imad shalaot, 2007).

**Durability Curve:** The remained percentage of Marshall Stability can be represented by durability curves, determined as follows. Firstly, the ratio ($M_O/M_t$) is identified, where: $M_O$ = the Initial Marshall stability at the start of a test (control samples) and $M_i$ = subsequent readings of Marshall Stability at the second test (one cycle). Secondly, this ratio is determined as the Marshall Stability ($M_i$) at the third test (two cycles) and so on until the fifth cycle. All of the remaining Marshall stabilities in our tests have been calculated and are tabulated in Table 3. Fig. 8 shows the durability curves of the basic AM, asphalt mixtures with LDPE, and asphalt mixtures with WPB (Imad shalaot, 2007). Polyethylene and waste plastic, where enhancing these materials in resistance against water damage and freeze-thaw change. The results stated that a one freeze-thaw cycle can be not represented actual behavior of mixtures. For example, the remained percentage of Marshall Stability for asphalt mixtures without additives after one cycle is 96 % of actual value of Marshall Stability, their counterparts of 92% for modified mixtures with polyethylene and modified mixtures with waste plastic, after 3 cycles asphalt mixtures without additives begin gradual failure more than other mixtures. The last cycle is only 44 % for asphalt mixtures without additives, while their counterparts of 56% for modified mixtures with polyethylene and 52% for modified mixtures with waste plastic. It is evident from the above results that adding polyethylene and waste plastic improve durability of modified mixture as was pointed out by both Paul and Bhattacharya in their research (Rajdip Paul and Debashis Bhattacharya, 2015).

## Durability index

**First Durability index (FDI):** The sum of slopes for successive parts in durability curve is called First Durability index (FDI). This value may be calculated from the following expression:

$$r = \sum_{i=0}^{n-1} \left(\frac{(s_i - s_{i+1})}{t_{i+1} - t_i}\right) = \frac{\Delta s}{\Delta t} \ldots Eq\ (1)$$

Where: r: First Durability index (FDI), $S_O$ = the remained percentage of the Marshall Stability at initial time ti, $S_i$ = remained percentage of Marshall stability at subsequent time t(i+1), ti ,t (i+1): number of freeze-thaw cycle, n: the number of the cycle being considered and the freeze-thaw cycle according to timetable (1, 2, 3, 4, and 5) cycles. The maximum remained percentage of Marshall stability to modified mixtures with polyethylene and waste plastic at five cycle due to improve the cohesion and adhesion properties that provide. The First Durability index (FDI) can be expressed as the percentage of the loss of stability per day. A positive value means that the stability is decreasing and a negative value means the stability increasing. Another procedure can be used to determine the First Durability index (FDI) – using the absolute ultimate value R as a percentage of the loss of Marshal Stability, as expressed in the following equation:

Where

S0 is the absolute value for the initial Marshal Stability. The First Durability index (FDI) which represent r and R was determined for the categories tested in this research using equations 1 and 2, respectively, and are shown in Table 4. Asphalt mixtures with polyethylene have a low (r) value of 30.86 %, while the r value for asphalt mixtures without additives was 55.22%. It can be noted that asphalt mixtures with waste plastic have an (r) value of 38.59%, which is approximately at the mid-point between the values of the other mixtures. Since the First Durability index (FDI) is expressed as the percentage of loss of Marshall Stability per day, asphalt mixtures with polyethylene have a lower loss rate in stability per day, followed by asphalt mixtures with waste plastic. This could be because adding the polyethylene and the waste plastic have improved the mixture's properties and in turn increased their durability, as mentioned by Pradeep soyal (13).

**Conclusion and Recommendation**

**Conclusion**

The practical examinations of conventional HMA and modified HMA presented many atisfactory results, especially the enhancements of the engineering properties of LDPE and WP asphalt mixture samples at optimum content compared to conventional asphalt samples. The optimum contents of the additives were found to be 4.1% for LDPE and 4.6% for WPB per weight of asphalt content. Modified asphalt mixes with LDPE and WPB have Marshall Stiffnessess higher than those of conventional mixes, at 81% and 57%, respectively, as adding polyethylene and waste plastic increases both adhesion and cohesion properties. Modified mixtures with LDPE have the lowest value of FDI, 30.86 %, followed by WP mixtures with an FDI of 38.59%, compared to asphalt mixtures with a value of 55.22%. These FDI values show that mixing LDPE and WPB into asphalt improve the engineering properties of the mixture and in turn increase the durability and service life when HMA and modified HMA mixtures are exposed to different freeze-thaw cycles.

**Recommendation**

More studies are suggested to determine the effects of long-term freezing-thawing cycles (e.g.10 cycles) on the engineering properties of modified asphalt mixtures. The study team suggests the use of an alternative industrial plastic (such as styrene-butadiene-styrene, or high density polyethylene and polypropylene) and waste plastic (such as drinking bottles, yoghurt pots and egg boxes). Further investigations are recommended to evaluate the use of recycled aggregate as an alternative to natural aggregates to minimize construction costs and to reduce environmental damages.

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